§8. Simulation Study of Compact Toroid Injection into Magnetized Plasmas

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To understand the fuelling process in a fusion device by the compact toroid (CT) injection method, we have carried out MHD numerical simulations where a spheromak-like CT (SCT) is injected into magnetized target plasmas [1]. It has been found that the SCT penetration into magnetized target plasmas is accompanied by complex physical dynamics, which is not simply described by the conventional simple theoretical model (CS model). One of the most remarkable phenomena is magnetic reconnection, which occurs between the SCT magnetic field and the target one. By examining the magnetic configuration in this process, we reveal that the reconnected target magnetic field experiences two different states. The first one is the *encroaching* state, where the target magnetic field lines encroach the SCT to peel its outermost reconnected field lines away. It disrupts the magnetic configuration of the SCT. In addition, the SCT penetrates with bending the target magnetic field in the injection direction. Thus, not only the magnetic pressure force but also the magnetic tension force decelerates the SCT. The second one is the *detaching* state, where the target magnetic field lines in the previous state again reconnect with other target magnetic field lines and detach the SCT. We can see that the transition between these two states relaxes the SCT deceleration caused by the magnetic tension force of the target magnetic field. By considering these complex processes, we represent the new theoretical model (NS model) to determine the SCT penetration depth [2]. If the z-axis is taken as the CT penetration direction, the equation of motion in the NS model is given by

$$\rho\frac{\partial V_z}{\partial t} = F - \frac{\partial}{\partial z}\frac{B^2}{2\mu_0} - \frac{B^2\pi\left(L_p + L_{SCT}\right)}{2\mu_0 R^2}\left(1 - e_{rec}\right) \qquad (1)$$

where L_{SCT}, L_p, R and e_{rec} are the half size of the SCT, the SCT penetration depth, the radius of the magnetized target plasma region and the relaxation rate, respectively. F is the acceleration force.

Figure 1 shows the time evolution of the SCT kinetic energy given by the simulation and the NS model [1,2]. Until about t = $27\tau_A$, the NS model with e_{rec} = 0 well coincides with the simulation result, after that, however, the relaxation of the SCT deceleration occurs. If we employ the relaxation rate e_{rec} after this time, we can adopt e_{rec} = 0.6. Figure 2 shows the state of the target magnetic field lines traced from any z-coordinate with (r, θ) = (R, 3π/2). Following the time with z = 0, the target magnetic field line firstly experiences the encroaching state and secondly the detaching state. We can see that the transition occurs at about $27\tau_A$, which coincides with the time when the relaxation of the SCT deceleration occurs. It means that the transition between states of the target magnetic field caused by magnetic reconnection relaxes the SCT deceleration.

From these results, it can be seen that the NS model well explain the SCT penetration process. However, we assume in the current simulation that the both ends of the target magnetic field are line-tied on the conducting wall, which would overestimate the deceleration of the SCT by the magnetic tension force. The dependence of this condition will be reported in our future work.

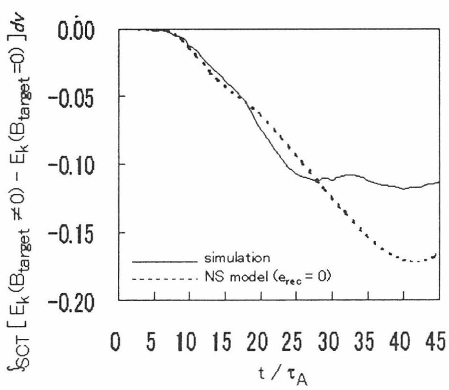

Fig. 1: The time evolution of the SCT kinetic energy in the NS model with e_{rec} = 0 and the simulation by subtracting them from the null target magnetic field case.

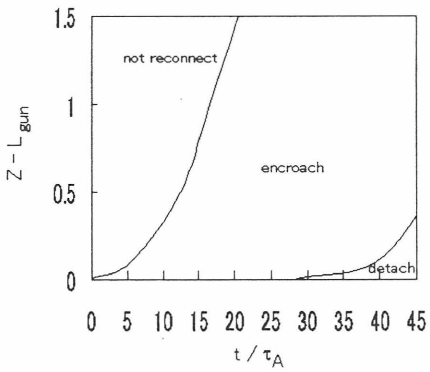

Fig. 2: The time history of the state of the target magnetic field lines traced from any z-coordinate with (r, θ) = (R, 3π/2). L_{gun} is the length of the gun region.

Reference
1) SUZUKI, Y., et al., Nucl. Fusion **40** (2000) 277.
2) SUZUKI, Y., et al., to be submitted in Phy.s Rev. Lett.